UHF-Dielectrometry of the Urine in Prognosis of Aggregation Stability

R. S. Bareeva, I. I. Turkovsky, L. M. Molodkina, B. A. Paramonov*, K. P. Pomorsky*, and A. B. Samatigo**

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Dielectric permeability of the urine from healthy subjects and patients with various types of urolithiasis was studied using millimeter electromagnetic waves. The urine from healthy subjects and patients with urolithiasis differed in dielectric properties, specific water content, and structure of water. A relationship was revealed between aggregation stability of urine colloids and dielectric properties of the urine in millimeter-wave electromagnetic radiation.

Key Words: *dielectrometry; water structure; colloidal systems; urolithiasis*

Hydration of urine components plays a key role in aggregation stability. However, urine samples from healthy subjects and patients with urolithiasis (ULT) were not studied in this respect. The structural organization of water in a multicomponent system of the urine remains unclear. No attention was paid to the hydrophobic interaction between individual components of the dry residue (*e.g.*, stone-forming crystals and colloids with water).

Ultrahigh-frequency (UHF) electromagnetic radiation can be used to study the supramolecular structure of aqueous systems, including biological fluids. It corresponds to the characteristic time of dipole polarization and maximum dispersion of dielectric permeability for liquid water [4]. The quasicrystalline structure and interaction of water with dissolved and colloidal components are evaluated from dielectric properties of simple and complex model systems and native solutions of biocolloids, including the blood, bile, and other transcellular fluids (at different levels of systemic organization) [3,5].

S. M. Kirov Military Medical Academy; *Research-and-Production Complex "High Technologies"; **St. Petersburg State Polytechnic Institute, Russia

Here we evaluated the relationship between dielectric properties of the urine in the UHF range and clinical and laboratory parameters of the urine for aggregation stability and stone formation (*i.e.*, urine lithogenicity).

MATERIALS AND METHODS

Dielectric properties of the urine were compared in healthy subjects (reference group, 29 urine samples) and patients with various forms of ULT (main group, 65 urine samples). The age (17-73 years) and sex of healthy subjects and ULT patients were not taken into account.

Dielectric properties of the urine were studied using a combination of waveguide and quasioptical method. A contact dielectric waveguide was matched with test medium. A special device allowed us to measure the amplitude and phase of the complex coefficient for reflection of ultralow-frequency millimeter waves (30 GHz) from the liquid medium during immersion of a matched dielectric waveguide. Contact waveguide was matched and calibrated by standard solutions of NaCl. Low-intensity radiation (radiant flux density at waveguide flange did not exceed 5 $\mu W \times cm^{-2}$) provided the absence of uncontrolled structural disturbances in the test object.

TABLE 1. Urine Analysis in ULT Patients and Healthy Subjects (mmol/liter)

Patients, value	K^+	Na^+	Ca^{+2}	Cl^-	P	Uric acid	Urates
Normal	35-90	150-220	2.5-7.5	115-220	29-45	1.2-7.1	before 0.7
Patients (n=20)							
minimum	18	60	1.9	24	4.2	2.3	0.08
maximum	100	216	6.4	348	40.2	7.1	1.88
average	36.8	141	3.1	156	19.6	3.2	0.68
Healthy subjects (n=6)							
minimum	28	120	2.7	75	9.7	2.3	0.51
maximum	66	192	6.7	316	39.5	5.9	1.0
average	34	140	3.2	164	24.2	3.6	0.62

The amplitude and phase of reflected waves from a perfectly matched load were used to calculate the real (ε') and imaginary components (ε") of complex dielectric permeability (Fresnel equation) [2]. The volume ratio of water (p) was estimated by the Maxwell—Wagner equation [7]:

$$|\varepsilon^*|=|\varepsilon^*_1|$$
$$|\varepsilon^*_i|(1\pm2p')\pm2|\varepsilon^*_1|(1-p')$$
$$|\varepsilon^*_i|(1-p')\pm2|\varepsilon^*_1|(1-p'/2),$$

where $|\varepsilon^*_i|$ is the modulus of dielectric permeability of solid residue (mixture of nonpolar dielectrics); $|\varepsilon^*_1|$ is the modulus of dielectric permeability of water; $|\varepsilon^*|$ is the modulus of dielectric permeability of solution; and p' is the volume ratio of solid residue ($p'=1-p$). The modulus of dielectric permeability was expressed as follows: $|\varepsilon^*|=|\varepsilon'-i\varepsilon''|=(\varepsilon'^2\pm\varepsilon''^2)^{1/2}$ [4]. The relative error was 1% (p>0.095).

RESULTS

Along with measurements of the dielectric properties of urine samples, we determined the concentration of major electrolytes (potassium, sodium, chlorine, calcium, and phosphorus), uric acid, and urates. Table 1 shows the minimum, maximum, and mean concentration of low-molecular-weight urine components, as well as the limits of normal.

The mean concentration of all components was similar in urine samples from healthy subjects and ULT patients (within normal). Microscopy of urine sediment revealed the presence of oxalate crystals and increased content of urates in 2 and 4 urine samples from ULT patients, respectively. No correlation was found between the presence of urinary stones and chemical composition of the urine. Total protein concentration in urine samples from healthy subjects and ULT patients was 12-40 μg/ml.

Combined study by means of clinical and instrumental methods allowed us to divide urine samples into highly lithogenic, lithogenic, low lithogenic, and non-lithogenic groups (according to the clinical course of ULT) [1]. Table 2 shows dielectric properties of urine samples and water at 30 GHz and 30°C.

Urine samples from healthy subjects and ULT patients differed in water content. The urine from ULT patients was more hydrated. The difference between derivatives of ε' and ε" (hydration para-

TABLE 2. Dielectric Properties of Selected Urine Samples (n=32, 8 Samples from Each Group) with a Certain Degree of Lithogenicity

Parameters	Water	Urine			
		highly lithogenic	lithogenic	low lithogenic	non-lithogenic
ε'	30.4±0.7	28.8±1.1	27.8±1.1	27.0±1.1	26.5±1.2
ε'	35.5±1.0	34.4±1.3	34.4±1.3	34.1±1.3	33.7±1.4
$\|\varepsilon^*\|$	46.7±1.2	44.9±1.7	44.3±1.7	43.5±1.7	42.9±1.8
$tgd=\varepsilon''/\varepsilon'$	1.17±0.01	1.19±0.02	1.21±0.02	1.27±0.02	1.27±0.02
p, %	100	95.62±1.10	94.17±1.10	92.35±1.10	90.89±1.00

Note. Temperature of samples during the measurement of dielectric properties was 30.0±0.2°C.

meters of lithogenic and non-lithogenic urine) is related to variations in water content and bound/free water ratio. For example, the dielectric loss tangent ($tg\delta$) more adequately reflects lithogenicity of urine samples than the volume ratio of water (*p*, Table 2). The dielectric loss tangent ($tg\delta$) decreases with decreasing the fraction of ice-like water in the aqueous system. The dielectric loss tangent was higher in non-lithogenic urine than in lithogenic urine. Hence, the volume ratio of structured water was higher in non-lithogenic urine [6].

Water content in non-lithogenic urine was lower than in lithogenic urine. These data indicate that non-lithogenic urine includes greater amounts of water molecules, which are not involved in dipole relaxation and have a limited number of rotational degrees of freedom due to the interaction with molecules of dissolved substances or surface of dispersed substances.

These data indicate that water content (*p* and $tg\delta$) significantly differs in urine samples from patients with progressive ULT and healthy subjects ($p<0.05$). Lithogenic urine from ULT patients with high-intensity stone formation differs in a higher volume ratio of water and lower dielectric losses in millimeter waves (30 GHz). Hence, the structuring of quasicrystalline water is higher in urine samples from healthy subjects. It should be emphasized that high structuring of water in the urine contributes to greater solubility of hydrophobic colloidal and mineral components in healthy subjects.

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